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ON NUCLEAR ENERGETICS AND β-ACTIVITY. III. THE GROUPS I=21 TO I=55.

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ABSTRACT The present paper is a summary of a work to be published shortly containing a detailed discussion of nuclei included in the isotopic groups I=21 to the end I=55. The object of this paper is to correlate the observed energy releases in β^-, β^+ and K-capture processes with the modified Weizsäcker-Bethe mass defect formula having an additional spin-dependent term, proposed by Prof M N. Saha and A. K Saha (1946). The authors have calculated the energy release in β^- and β^+ emissions according to Weizsäcker-Bethe formula for the nuclei in these groups and compared them with the observed energy releases so as to observe the effect of the spin dependent term. A general agreement with the newly proposed formula is found though the available data is too meagre for many groups specially in the rare-earth region The probable activities and energetics of still unknown nuclei are predicted in the light of newly proposed formula together with their methods of production It is, however, found that a varying value of β in the mass defect formula is much more satisfactory than a constant value and an empirical curve of β as a function of I is derived.

1. INTRODUCTION

This paper is in continuation of two previous papers on "Nuclear Energetics and β-activity" by Prof. M. N. Saha and A. K. Saha (1946) (Paper I) and A. K. Saha, Ghoshal and Das (to be published shortly) (Paper II). In the first paper Prof. Saha and Saha (Jr.) modified the Weizsäcker-Bethe mass defect formula by an additional spin-dependent term and observed energy-releases were explained satisfactorily for groups $I=-1$ to $I=6$ in Paper I and $I=7$ to $I=20$ in Paper II. The present paper is a summary of a large work to be published shortly containing a systematic and critical study of β-activity and K-capture process for groups $I=21$ to $I=55$. The nuclei have been arranged in isotopic groups in the Nuclear Chart* (Fig. 1), from which certain β-stability rules (Saha, Sirkar and Mukherjee, 1940) can be studied. In the first section the observed energy releases in β-activities are discussed element by element, of which only two elements are included in this summary. In the next section the β-instability of the nuclei

* Since the completion of this work, a number of new isotopes, radio-active as well as stable, have been discovered. These are to be supplemented in the Nuclear Chart. These are: La^{138}, stable, 089% abundance [Inghram et al, 1947, Phys Rev. **72**, 967]; Bi^{204}, 12hr. (K-capture); Bi^{206}, 6.4*d* (K-capture); Po^{206}, 9*d* (K-capture & α); Po^{207} 5 7h (K-capture & α); Po^{208}, ~3yr (α). [Templeton et al, 1947, Phys. Rev. **72**, 768, 758]; Bi^{210} (RaE) α Ti^{206} (4 23m) [Broda & Feather, 1947, Proc Roy Soc **A190**, 20].

is discussed in order of different I groups. The energy releases of the nuclei are calculated according to Weizsacker-Bethe formula and these are given in form of A^- and A^+ curves for different I groups. The energetics of known and unknown nuclei are studied according to the new formula.

The notations and symbols used are same as in Paper I and Paper II.

2 DISCUSSION OF ENERGY-RELEASES

Out of the discussion of 47 elements, $_{50}$Sn to $_{96}$Cm, we select in the present extract the following elements, $_{55}$Cs and $_{93}$Np as the typical illustration of the method of study followed.

$_{55}$Caesium.

(Tables 1.1 and 1.2)

Cs^{125}. Not yet produced. May be obtained from .094% Xe^{124} (p, γ) (d, n) Cs^{125} reaction. The very low frequency of the target and the difficulty of using a gaseous target renders the possibility of carrying out the experiment rather remote.

Cs^{126}. Not known. Cannot be produced by usual reactions.

Cs^{127}: Not yet produced May be produced by .088% Xe^{126} (p, γ) (d, n) Cs^{127}. The difficulties of production are the same as with Cs^{125}.

Cs^{128}. Not yet produced. May be produced by .101% Ba^{130} (d, α) Cs^{128} The yield will be very low due to low abundance of the target.

Cs^{129}. Not yet produced. May be produced by reaction, 1.9% Xe^{129} (p, n) $(d, 2n)$

TABLE 1.1

Production Table of Cs.

	Target		Reaction	Product		Half-life
	Element	Isotopes		Element	Isotopes	
1	Cs	133	(n, γ)	Cs	134	3h(−), 1.7y(−)
2	Ba	130, 132, 134, 135, 136, 137, 138	(n, p)	Cs	130, 132, 134, 135, 136, 137, 138	33m(−)
3	Cs	133	(d, p)	Cs	134	3h(−), 1.7y(−)

TABLE 1.2

Cs

Nucleus	Half-life	Assignment class	E_β (Mev)	E_γ (Mev)	Energy-release E (Mev)
Cs^{125}	...				
Cs^{126}	×				
Cs^{127}					
Cs^{128}	..				
Cs^{129}					
Cs^{130}	..				
Cs^{131}	10 d (K)	A		.145 (γ) .031	
Cs^{132}	...				
Cs^{133}	Stable (100%)				
Cs^{134}	3h ( ) 1 7y (−)	A A	1.0 .658, ~.09	.568, .602, .794	1 0 2 054
Cs^{135}	>2 5 × 10⁴y ( )	A		...	...
Cs^{136}	13d (−)	B	.28	1 2	1 48
Cs^{137}	33y (−)	A	5, .8	7	...
Cs^{138}	33m (−)	B	2 6	1 2	3 8
Cs^{139}	7m (−)	A	...	...	
Cs^{140}	40s (−) Short (−)	B A			
Cs^{141}	Short (−)	B	...	...	..
Cs^{142}	~1−2m (−)	B	...	...	...
Cs^{143}	Short (−)	A		.	..
Cs^{144}	Short (−)	A		...	..
Cs^{145}	Short (−)	B		..	...

Cs^{129}. The above-mentioned difficulties are present in the production of this nucleus.

Cs^{130} : Not yet produced. Should be obtained from the reaction, 100% I^{127} (α, n) Cs^{130}, provided α-particles of sufficient energy are available.

Cs^{131} : This nucleus is interesting as it shows consecutive K-capture process. A 10*d* (K) activity obtained from 11.7*d* K-active Ba^{131} is assigned to Cs^{131} as reported by Yu, Gideon and Kurbotov (1947). It emits .145 Mev γ-rays that are strongly converted (97%) giving .112 Mev electrons. X-ray of 30 Kev energy is also reported. Katcoff (1947) studied this nucleus and found no γ-ray associated with 10.2*d* Cs^{131}. The X-ray energy was measured as 30.8 Kev. The mass assignment is made unique by him with the help of critical absorption measurements by Finkle (1947).

Cs^{132} : Not yet produced. May be produced by the reaction 26.96% Xe^{132} (p, n) Cs^{132}. The fairly good frequency of Xe^{132} renders the possibil-
$(d, 2n)$
ity of the reaction quite good.

Cs^{134} : Activities of 3h(−) and 1.7y(−) are uniquely assigned to Cs^{134}. Kalbfell and Cooley (1940) obtained a 1 Mev β-ray associated with the 3h(−) activity and a .9 Mev β-ray with 1.7y(−) activity by absorption method. Presence of γ-rays associated with the latter activity is reported but no measurement has been done by him. Eliott and Bell (1947) studied 1.7yr. Cs^{134} with magnetic lens spectrometer together with coincidence techniques and obtained two β-spectra having end-energies of .658 Mev and ~.090 Mev. Three γ rays of energies .568, .602 and .794 Mev were obtained. According to the level-scheme suggested by him, energy-release, E^- comes out as 2.054 Mev. This is in agreement with the values of Siegbahn and Deutsch (1947) who observed major disintegration by ·645 Mev β-rays followed by two γ-rays of .584, ·776 Mev, the total energy-release being 2.005 Mev. For the 3h(−) period energy release E^- may be taken as ~1 Mev.

Cs^{135} : Produced so far only in fission having a period $>2.5\times10^4$y(−). May be obtained from the reaction, 10.54% Xe^{134} (p, γ) Cs^{135}. No
(d, n)
measurement of β-energy has yet been done. The identification is in agreement with Saha-Saha theory as the nucleus is on the flank of the group of stable nuclei in the group I=25.

Cs^{136} A 13 d(−) activity obtained from fission and decaying to stable Ba is assigned vaguely to Cs^{136}. It is difficult to assign properly the activity from fission and the reactions, 100% La^{139} (n, α) Cs^{136} and 8.95% $Xe^{136}(p, n)$ Cs^{136} should be tried. Finkle et al (1946) determined $E_{\beta^-}\sim 0.28$ Mev by absorption in Al and $E_\gamma=1.2$ Mev by absorption in Pb. E^- may be taken as ~1.48 Mev.

Cs^{137} : A 33y(−) activity obtained so far only in fission-chain is uniquely assigned to Cs^{137}. May be produced also by reaction, 11.32% Ba^{137} (n, p) Cs^{137}.

According to Plutonium Project Report (1946) the mass-assignment has been done mass-spectroscopically. Glendenin and Metcaff (1946) observed two β-rays of energies 0.5 Mev (50%) and 0.8 Mev (50%) by absorption in Al, using Feather's relation. Both β-transitions are of 3B class. A γ-ray of energy .75 Mev has also been obtained by them by absorption in Pb. Metcalf et al (1944) previously obtained values of 0.8 Mev and $\sim$0.4 Mev for β-rays and 0.7 Mev for γ-ray. With the available data it is not possible to arrive at a satisfactory level-scheme and possibly another γ-ray is missing. This requires further investigation.

Cs^{138} : A 33 m $(-)$ activity is obtained from reaction (2) and also from fission. Since Ba has a number of stable isotopes nothing definite about mass can be said from this one reaction and none in the fission-chain definite.

Glasoe and Steigman (1940) measured $E_{\beta^-} = 2.6$ Mev by absorption in Al. Glendenin and Metcalf (1946) measured $E_\gamma = 1.2$ Mev by absorption in Pb. E^- may be taken as 3.8 Mev.

Cs^{139} : It has so far been obtained only in fission having 7m $(-)$ activity uniquely assigned. It cannot be produced by usual reactions. No energy measurement is done yet.

Cs^{140} : One 40s $(-)$ activity obtained so far only in fission is assigned to Cs^{140}. No chain could be established for the activity and the assignment is vague. A "short" $(-)$ activity descendant of 16s Xe^{140}, is assigned to Cs^{140} uniquely. No energy measurement has been done for either activity.

Cs^{141} : A short $(-)$ activity obtained from fission, as descendant of 3s $(-)$ Xe^{141}, is ambiguously assigned to Cs^{141}. None in the chain is definite and this cannot be produced by usual reactions. No energy measurement has been done yet.

Cs^{142} : A 1-2m $(-)$ activity obtained from fission only, is assigned vaguely to Cs^{142} as none in the chain definite. Cannot be produced by usual reactions. No energy measurement has been done.

Cs^{143} : A short $(-)$ activity obtained from fission is uniquely assigned to Cs^{143}. No energy measurement has been done yet.

Cs^{144} : A short $(-)$ activity is obtained from fission-chain. This has been uniquely assigned to Cs^{144}. No energy measurement has been done.

Cs^{145} : A "short" $(-)$ activity obtained from fission as descendant of 8s $(-)$ Xe^{145} is assigned to Cs^{145}. None in the chain is definite and this cannot be produced by usual reactions. No energy measurement has been done.

$_{93}$Neptunium

So far, six isotopes of Np are reported by Seaborg (1946). Some of them are produced by bombardment with 22 Mev deutrons and 44 Mev α particles obtained from Berkeley Cyclotron. With such high energy interesting reactions *viz.*, $(d, 3n)$, $(d, 4n)$, $(\alpha, p3n)$, $(\alpha, p4n)$, $(\alpha, 3n)$ etc. are found to occur.

(TABLES 2.3 AND 2.2)

Np^{232} : This is not yet known. May be produced by the reactions U^{233} $(d, 3n)$ Np^{232}, since U^{233} has now been produced and isolated in
$(d, p4n)$
weighable amounts. This is expected to be β^{+}-active.

Np^{233} . This is not yet known. May be produced by the reactions U^{235} $(d, 4n)$ Np^{233} and U^{233} $(d, 2n)$ Np^{233}. Probable activity of this
$(\alpha, p3n)$
isotope is K-capture or β^{+} emission.

Np^{234} : This 4.4 d period K-capturing isotope was prepared by the following reactions : U^{235} $(d, 3n)$ Np^{234}; Pa^{231} (α, n) Np^{234} ; and U^{235} $(\alpha, p4n)$ Np^{234}. A γ-ray has been detected from this nucleus, but the energy is not measured. The K-capture process is in agreement with the stability rules.

Np^{235} : A 240 d K-capturing isotope has been prepared by the following reactions . U^{235} $(d, 2n)$ Np^{235} and U^{235} $(\alpha, p3n)$ Np^{235}. No energy measurement has been yet done. This activity is also in agreement with the theory.

TABLE 2.1

Production Table of Np.

	Target		Reaction	Product		Half-life
1	U	235	(d, n)	Np	236	20h (−)
2	U	235	(d, 2n)	Np	235	240d (K)
3	U	238	(d, 2n)	Np	238	2d (−)
4	U	235	(d, 3n)	Np	234	4.4d (K)
5	U	238	(d, 4n)	Np	236	20h (−)
6	Pa	231	(α, n)	Np	234	4.4d (K)
7	U	235	(α, p)	Np	238	2d (−)
8	U	235	(α, p2n)	Np	236	20h (−)
9	U	235	(α, p3n)	Np	235	240d (K)
10	U	238	(α, p3n)	Np	238	2d (−)
11	U	235	(α, p4n)	Np	234	4.4d (K)

TABLE 2.2

Nucleus	Half-life	Assignment Class	E_β (Mev)	E_γ Mev	Energy-release E (Mev)
Np^{232}	...	...			
Np^{233}	...	...			
Np^{234}	4.4d (K)	A			
Np^{235}	240d (K)	A			
Np^{236}	20h (−)	A			
Np^{237}	2.25×10^6y(α)	A			
Np^{238}	2d (−)	A			
Np^{239}	2.3d (−)	A	47	.22, .27	
Np^{240}	...	...			
Np^{241}	...	...			

Np^{236} : A 20 h (−) activity is associated with Np^{236}. This was prepared by the following reactions: U^{235} (d, n) Np^{236} ; U^{238} $(d, 4n)$ Np^{236} ; U^{235} $(\alpha, p2n)$ Np^{236}. No measurement of β-energy is done yet.

Np^{237} : Np^{237} is an α-active nucleus of 2.25×10^6y half-life being the descendant of 500 y (α) Am^{241}. This is the most stable isotope of Np. This has been isolated in weighable amounts and is used as target.

Np^{238} : This is the second transuranic nucleus obtained by Seaborg in 1940. A 2.0 d β-active Np^{238} is obtained from the following reactions: U^{238} $(d, 2n)$ Np^{238} ; U^{238} $(\alpha, p3n)$ Np^{238} and U^{235} (α, p) Np^{238}. Nothing is reported about β-energy.

Np^{239} : The 23d (−) Np^{239} is the first transuranic element discovered by McMillan and Abelson (1940) as the decay product of 23m (−) U^{239} which was formed by U^{238} (n, γ) reaction. They measured β -energy as .47 Mev. and γ-energies as .22 and .27 Mev by β-spectrograph. The energy-release E^- comes out as .96 if the γ-rays are assumed to be in cascade being genetically related to the β-emission. This value of E^- is higher than expected from Saha-Saha theory and more definite information about E^- is required.

Np^{240} : Not yet known. May be obtained by the rare reaction U^{238} (α, pn) Np^{240}.

Np^{241} : Not yet known. May be prepared from U^{238} (α, p) Np^{241} reaction.

This discussion of Np shows that the stability rules hold good also in the transuranic region.

3. DISCUSSION OF A^- AND A^+ CURVES

In this section the observed energy-releases are compared with the A^- and A^+ curves. These curves are drawn with the formulae given in Paper I. These are enlisted below for easy reference.

$$\Delta M = \alpha A - \beta \frac{I^2}{A} - \gamma A^{\frac{2}{3}} - \delta \frac{Z^2}{A^{\frac{1}{3}}} + \lambda (Z, A)$$

$$E^- (Z, A) = A^- (Z, A) + \lambda (Z+1, A) - \chi (Z, A)$$

where

$$A^- (Z, A) = .766 + \frac{4\beta(I-1)}{A} - \frac{.58(A-I+1)}{A^{\frac{1}{3}}} \text{ Mev.}$$

β is taken as 19.5, 18.9 or 17.4 Mev.

$$E^+ (Z, A) = A^+ (Z, A) + \chi (Z-1, A) - \chi (Z, A)$$

where

$$A^+ (Z, A) = -1.788 - \frac{4\beta (I+1)}{A} + \frac{.58 (A-I+1)}{A^{\frac{1}{3}}} \text{ Mev.}$$

$$E^k = E^+ + 2m - \tfrac{1}{2} m \alpha^2 Z^2$$
$$\simeq E^+ + 2m$$

$I = \text{even}$

For $Z = \text{even}$, $N = \text{even}$ ... $E^- = A^- + \chi (Z+1, A) < A^-$

$E^+ = A^+ + \chi (Z-1, A) < A^+$

For $Z = \text{odd}$, $N = \text{odd}$ ... $E^- = A^- - \chi (Z, A) > A^-$

$E^+ = A^+ - \chi (Z, A) > A^+$

$I = \text{odd}$

$E^- \simeq A^-$

$E^+ \simeq A^+$

Out of the discussion of 35 I groups, three groups, two odd and one even, are included here as typical illustration.

$I = 21.$

This group extends from Kr^{93} to Eu^{147} with several gaps and many undiscovered nuclei as seen in the Nuclear Chart (Fig. 1). The stable region includes Sb^{123} to Xe^{129}. The nuclei in the left flank of Sb^{123} are β^--active while those on the right of Xe^{129} show K-capture or β^+activity. The stability rule of Saha, Sirkar and Mukherjee (*loc. cit.*) is thus obeyed in this group. The gaps indicate that the corresponding nuclei cannot be obtained with known reactions except by fission. The energetics of the nuclei are discussed below one by one.

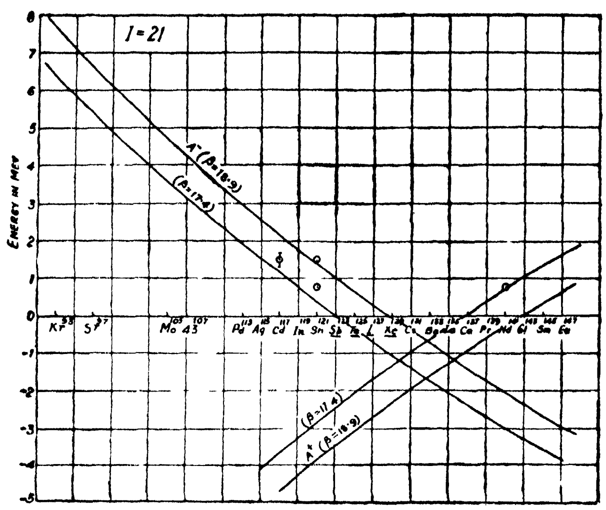


FIG. 2

Kr^{93}, Sr^{97}, Mo^{105}, 43^{107} :

These short-lived β^--active nuclei have been obtained in fission ; but their energy releases have not yet been measured. They will decay with high energy releases as given in A^- curve, since $E^- \simeq A^-$. As discussed below, A^- curve with $\beta = 17.4$ is more suitable that the other curve.

Cd^{117} :

A 2.8h $(-)$ activity is uniquely assigned to Cd^{117}. The energy is given as 1.3 to 1.7 Mev. and nothing is reported about γ-rays (Lawson and Cork, 1940). Energy-release, E^- is $\simeq 1.5$ Mev. or greater. This point falls somewhat below the A^- curve with $\beta = 18.9$, but is closer to $\beta = 17.4$ curve and is in fair agreement with the latter.

Sn^{121} :

Two activities 62h $(-)$ and 130d $(-)$ are ambiguously assigned to Sn^{121}. Corresponding values of E^- are .76 Mev and $\simeq 1.5$ Mev. The 130d $(-)$ activity may belong to Sn^{123}. Now $E^- = .76$ Mev agrees well with A^- curve with $\beta = 17.4$; and $E^- = 1.5$ Mev agrees with A^- curve having $\beta = 18.9$ in $I = 21$, but if this is assigned to Sn^{123} it agrees well with A^- curve with $\beta = 17.4$ in $I = 23$. In this region $\beta = 17.4$ being more satisfactory, from other considerations, 62h $(-)$ and 130d $(-)$ activities most probably belong to Sn^{121} and Sn^{123} respectively.

Sb^{123}, Te^{125}, I^{127}, Xe^{129} :

These stable nuclei are expected to occur in the region where both A^- and A^+ are negative (A^+ lying between -1.02 and 0, however, includes the possibility of K-capture). The A^- and A^+ curve with standard value of $\beta = 18.9$, flagrantly violates this condition. It is found that a lower value of $\beta = 17.4$, justifies the positions of the stable nuclei and is in agreement with the measured energy-releases in this group.

Cs^{131} :

Recently a K-capture activity of this nucleus has been reported (Yu, et al, 1947)). The value of A^+ is -1.0 Mev with $\beta = 17.4$ curve, and A^+ is equal to -2.0 Mev if $\beta = 18.9$ curve is considered. So K-capture process is possible with $\beta = 17.4$ curve while $\beta = 18.9$ definitely excludes K-capture energetically. Thus $\beta = 17.4$ value is in good agreement with observed fact. The absence of any γ ray as observed by Katcoff (1947) follows from the theory since energy-release, E^k is comes out as very small.

Ba^{133} :

A K-capture process is definitely assigned to Ba^{133}. A^+ curve with $\beta = 18.9$ makes this process improbable whereas A^+ curve with $\beta = 17.4$ makes K-capture quite possible since $A^+ = -.65$ in this case.

La^{135} .

A K-capture activity is probable for this still unknown nucleus.

Ce^{137} .

This isotope is expected to show K-capture or small β^+ activity.

Pr^{139} :

A β^+-activity is more probable than K-capture for this nucleus.

Nd^{141} :

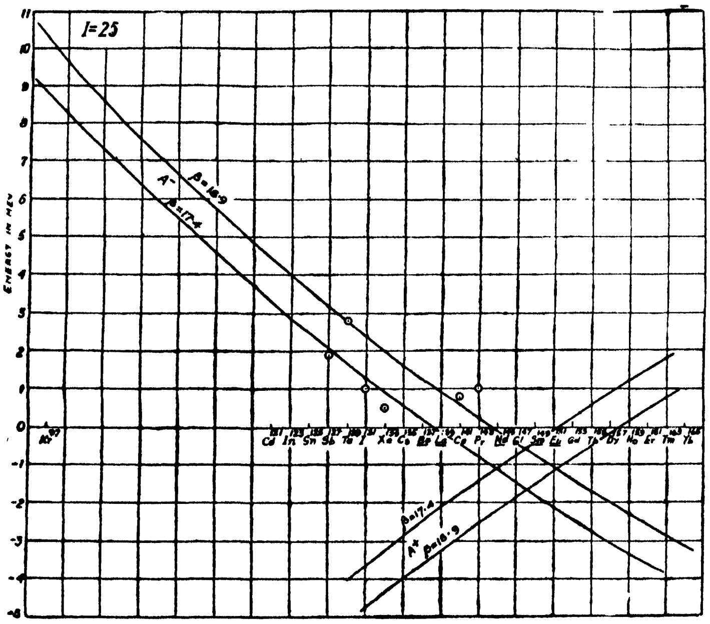
This uniquely assigned nucleus shows β^+ activity and the energy-release, E^+ is .78 Mev. This point is in good agreement with A^- curve having $\beta = 17.4$.

The nuclei on the right side of Nd^{141} are all expected to be β^+-active.

Thus we see that the agreement with Saha-Saha formula is good with the value of $\beta = 17.4$ but not with the value of $\beta = 18.9$. Such a smaller value of β is found satisfactory for a few groups in this region. This variation of the value of β with I is of much importance and will be discussed at the end of the present paper.

$I = 25$.

This group extends from Cd^{121} to Yb^{165} with a solitary nucleus Kr^{97} obtained from fission, in the extreme left. The stable nuclei are included between Ba^{137} to Eu^{151} with the exception of Ce^{141}, Pr^{143} and 61^{147} which show β^--activities. These three nuclei violate Saha, Sirkar and Mukherjee stability rule as their assignments, being arrived at mass-spectroscopically, are unique. The nuclei on the left of Ba^{137} show β^--activity.



F·G. 3

Sb^{127} : The E^- value for this uniquely assigned nucleus is 1.87 Mev. This point falls much below the A^- curve ($\beta = 18.9$). This value is, however, in good agreement with A^- curve having $\beta = 17.4$.

Te^{129} : The value of E^- for this uniquely assigned nucleus is $\simeq 2.88$ Mev. This value is in agreement with A^- curve having $\beta = 18.9$ and falls much above the shifted curve ($\beta = 17.4$).

I^{131} . The energy-release E^- for this uniquely assigned nucleus is 1.042 Mev. This point being far below the A^- curve with $\beta = 18.9$, agrees well with the shifted curve with $\beta = 17.4$.

Xe^{133} : This nucleus is uniquely assigned. The energy-release $E^- = .489$ Mev. This value is much smaller than the A^- value with $\beta = 18.9$, but agrees well with the shifted curve with $\beta = 17.4$.

Ba^{137}, La^{139} : The position of these two stable nuclei cannot be justified with A^- curve with $\beta = 18.9$. since A^- is highly positive. The shifted curve with $\beta = 17.4$, however, justifies their stability.

Ce^{141} : The assignment is unique. The value of $E^- = .86$ Mev. The activity of this nucleus is a violation of stability rule as evident from its position.

Pr^{143} . This β-active nucleus is uniquely assigned. $E = 1.0$ Mev. This activity of Pr^{143} is a violation of stability rule.

Thus we see that A^- curve with $\beta = 18.9$ do not satisfy Saha-Saha theory at all. The A^- and A^+ curves with $\beta = 17.4$ is in good agreement with theory for all the nuclei whose energies have been measured excepting Te^{129}. The stable nuclei starting from Ba^{137} and ending in Eu^{151} fit fairly well with the curves with $\beta = 17.4$.

$I = 28.$

This group extends from Sb^{130} to Ta^{174}. This group exhibits some exceptions to Saha, Sirkar and Mukherjee stability rules. Xe^{136} is an even-even nucleus and is stable. The following even-even nuclei, $_{56}Ba^{140}$ and $_{58}Ce^{144}$, expected to be stable are both β^--active. Of these Ba^{140} is uniquely assigned and is very well-studied since Hahn's pioneer work on fission. The other one Ce^{144} is also uniquely assigned. All the remaining nuclei obey stability rules. Now we discuss the nuclei whose energy values are available, one by one.

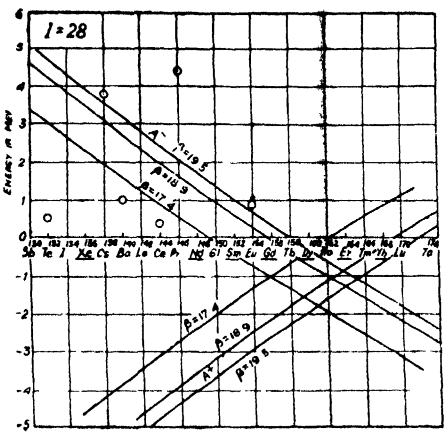


FIG. 4

Te^{132} : The assignment is vague. This nucleus being even-even, shows β^--activity since it falls further left. The A^- value is so large that even a large subtraction of λ-term cannot make E^- $-$ve. A small E^- value .5 Mev. is an interesting and good agreement with Saha-Saha theory. Hence the assignment may be taken correct.

Cs^{138} : The assignment is vague. The value of E^- is 3.8 Mev This point falls somewhat above A^- curve ($\beta = 18.9$) as expected for odd-odd nuclei.

Ba^{140} : This uniquely assigned nucleus is an exception to the stability rule, as we have mentioned above. The energy release E^- is 1 Mev which, however, falls below the A^- curve satisfying the characteristic feature of radio-active even-even nucleus.

La^{142} : The energy-measurement of this vaguely assigned nucleus is incomplete. It is expected to give a high energy-release, being much greater than A^- value.

Ce^{144} : This uniquely assigned nucleus gives an energy release of .348 Mev. This point falls much below the A^- curve ($\beta = 18.9$) satisfying the characteristic condition for radio-active even-even nucleus, given by the theory.

Pr^{146} : The assignment is vague. $E^- \simeq 4.4$ Mev which comes much above the A^- curve ($\beta = 18.9$), in agreement with the theory. Hence the assignment is most probably correct.

Eu^{154} : The energy-measurement of this vaguely assigned nucleus is incomplete. Since the γ-ray energy is not known, E^- will be greater than .9 Mev. This is in agreement with the theory.

Now we discuss the nuclei with isobaric stable nuclei on either side.

I =	30	ONd	OSm	OGd	ODy
	28	O61	ρ Eu	δ Tb ?	OHo
	26	OSm	OGd	ODy	OEr
	A →	150	154	158	162

61^{150} : Assuming that both transitions take place from the same level of the nucleus in question, $E^+ - E^- = A^+ - A^-$. $E^+ - E^- = -3.15 - .91 = -4.06$. So it is expected that 61^{150} will be β^--active having energy release $E^- \sim 3.5$ Mev if $\chi(61, 150)$ is of the same order as $\chi(59, 146)$. However, we have seen that on the spin-dependent term of Pr is much larger than that of average nuclei. β^+-activity, too, can occur if $E^- > 4.06$ Mev which is rather improbable; if E^- lies between 3 and 4 Mev, K-capture can take place. So dual activity is expected under above condition.

Eu^{154} : $E^+ - E^- = -2.47 - .25 = -2.72$ Mev. We know that $E^- > .9$Mev. If E^- comes out > 2.72, positron activity also, becomes a possibility; if $1.7 < E^- < 2.7$, K-capture can take place. This nucleus demands further investigation.

Tb^{158} : $E^+ - E^- = -1.81 + .3 = -1.51$ Mev. The suggested positron-activity of this nucleus is not very probable. β^--activity should exist and only if E^- is > 1.5 Mev, β^+-activity may accompany β^--activity. K-capture process is a probable one since it can occur if $E^- > .5$ Mev. This requires further investigation.

Ho^{162} : $E^+ - E^- = -1.15 + 1.02 = -.13$. This undiscovered nucleus is very interesting since both β^- and β^+-activities and K-capture are expected from this nucleus.

Tm^{166}, Lu^{170}, Ta^{174} : These three nuclei are expected to show β^+-activity, or K-capture, or both.

Thus we see that this group agrees well with Saha-Saha theory, though there is some anomaly about the activities of Ba^{140}, and Ce^{144}. These exceptions can be interpreted as follows. For ${}_{52}Te^{132}$ and ${}_{54}Xe^{136}$, the spin-dependent terms $\chi(53, 132)$ and $\chi(55, 136)$ are large and of the same order so that E^- for ${}_{52}Te^{132}$ is small +ve and E^- for ${}_{54}Xe^{136}$ is −ve. But spin-dependent terms of $_{56}Ba^{140}$, and $_{58}Ce^{144}$, $\chi(57, 140)$, $\chi(59, 144)$ are of same order but are smaller than previous values. This makes them β^--active instead of being stable but E^- much smaller than A^- ($\beta = 18.9$). This is shown below.

	Te^{132}	Xe^{136}	Ba^{140}	Ce^{144}
A^- in Mev.	4.23	3.45	2.67	1.95
E^- in Mev.	·5	−ve	1.0	·35
$-\chi(Z+1, A)$	3 73	>3.45	1 67	1.65

Similar anomaly has been found in group I=8. After stable $_{20}Ca^{48}$, three even-even nuclei $_{22}Ti^{52}$, $_{24}Cr^{56}$ and $_{26}Fe^{60}$ do not occur as stable isotopes. This has been discussed in details by Saha and Saha (1946) in paper I.

4. DISCUSSION OF β-VALUE

From the discussion of all the I groups, of which three are given above, a general agreement of the proposed formula is obtained qualitatively with the data available at present although there are some anomalies for a few nuclei. The important point in the study of energetics in the present paper, as well as in Paper I and Paper II, is the value of β in the mass defect formula. In the conclusion of three papers we observe that different values of β besides the standard value, 18.9 are found to be satisfactory for different regions of I groups, as given below.

$$
\begin{aligned}
I &= -1 \text{ to } I = 6\,; & \beta &= 19.5 \text{ Mev.}\\
I &= 7 \text{ to } I = 20\,; & \beta &= 18.9 \text{ Mev.}\\
I &= 21 \text{ to } I = 26\,; & \beta &= 17.4 \text{ Mev.}\\
I &= 27 \text{ to } I = 50\,; & \beta &= 18.9 \text{ Mev.}\\
I &= 51 \text{ to } I = 55\,; & \beta &= 19.5 \text{ Mev.}
\end{aligned}
$$

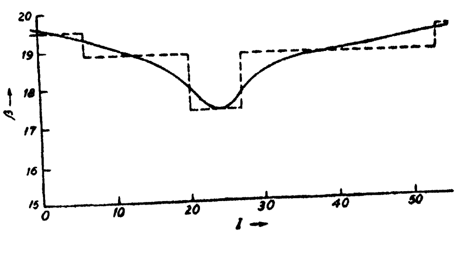


FIG. 5

Thus an approximate continuous curve of β can be plotted against I (Fig. 5) which passes through a minimum in the central region. This indicates that the value of β is not constant but is a function of I given by the above type of curve. The expression for the function is yet to be obtained.

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